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A METEOROLOGICALLY DRIVEN MAIZE STRESS INDICATOR MODEL

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16. Abstract

A maize soil moisture and temperature stress model described herein was developed to serve as a meteorological data filter to alert commodity analysts to potential stress conditions in the major maize-producing areas of the world. The model also identifies optimum climatic conditions and planting/harvest problems associated with poor tractability.

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TECHNICAL MEMORANDUM

NO.

A METEOROLOGICALLY DRIVEN MAIZE STRESS INDICATOR MODEL

EARLY WARNING/CROP CONDITION ASSESSMENT

UNITED STATES DEPARTMENT OF AGRICULTURE
HOUSTON TEXAS

UNITED STATES DEPARTMENT OF AGRICULTURE

AGRISTARS-EARLY WARNING/CROP CONDITION ASSESSMENT

A METEOROLOGICALLY DRIVEN MAIZE STRESS INDICATOR MODEL

FIRST ISSUE

1. REASON FOR ISSUANCE

Document the development of a model capable of giving an early indication of actual or potential plant stress due to moisture and temperature.

2. COVERAGE

The moisture/temperature values which both stress and optimize the vigor of maize by specific growth stages are reviewed. A description of the model structure and stress parameters are set forth. Model output and preliminary results are discussed.

3. PREPARED BY

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METEOROGICALLY DRIVEN MAIZE STRESS INDICATOR MODEL

PART 1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this section is to document a corn hazard model that detects plant stress due to moisture deficiency and adverse temperatures. A brief synopsis of the climatic stress thresholds for corn (maize) at different growth stages is also given.

1.2 SITUATION

USDA policy is to provide American farmers and commodity analysts with the most timely information concerning world and national agricultural activities. Early Warning/Crop Condition Assessment, located in Houston, Texas is one of eight projects of the AgRISTARS program. AgRISTARS is the program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing and is a cooperative effort of 5 Federal agencies. These agencies are: Department of Agriculture (USDA); National Aeronautics and Space Administration (NASA); Department of the Interior (USDI); and the Agency of International Development (USAID).

Early warning of changes affecting production and quality of commodities and renewable resources is the number one priority area of the Secretary's Initiatives. The overall objective of the EW/CCA Project is to provide a capability for the USDA to respond in a timely manner to factors which affect the quality and production of economically important crops. The response will involve identifying the occurrence of environmental and agronomic factors which influence crop condition and determine the severity of the area affected. This research activity will be directed toward tecniques which will augment and strengthen the operational Crop Condition Assessment Division (CCAD) of the Foreign Agricultural Serivce (FAS) and provide new analysis tools to domestic users in USDA.

The CCAD operations plan calls for assessment based on a convergence of evidence from all sources. In 1981, this consists of the traditional sources plus increased use of agrometeorological models that can be used to infer crop conditions and initial subjective operational use of remote sensing techniques.

A corn indicator stress model was developed to alert a crop analyst of a potential problem area. The model utilizes meteorological data because it is generally available much sooner than Landsat data, and provides daily data versus the eighteen day interval data from Landsat. This model eliminates the necessity of spending time and resources to concentrate on areas which the model indicates have

high probability that stress is occurring or is likely to occur. After a potential stress area has been identified, an analyst can assess the condition using meteorological, Landsat, and ancillary data. This model is not intended as a stand-alone system, but rather, an indicator to a crop analyst to initiate an investigation of the area.

The CCAD mission of alert analysis requires a quick response system and will sacrifice exact quantative results to meet their response requirement. A subjective estimate, if timely, which provides information in general terms such as better or worse than last year and an approximate percentage is very useful in assessing an alert situation. As research provides better tools, it is believed that these subjective estimates can be quantitatively accurate.

PART 2.0 STRESS FUNCTIONS

2.1 MAJOR VARIABLES

The degree of stress is dependent on three variables - phenological growth stage, available soil moisture and temperature.

2.2 The Hanway Growth Stage (HGS) system (Hanway, 1963) was used in the model as defined below:

HGS	PHENOLOGICAL STATE
0.0	Emergence
1.0	4 Leaves
2.0	8 Leaves
3.0	12 Leaves
4.0	16 Leaves
5.0	Silk-tassel
6.0	Blister Kernel
7.0	Dough
8.0	Begin Dent
9.0	Full Dent
10.0	Physiological Maturity

During each stage optimum and stress condicitions exist. Most of these conditions are directly related to meteorological factors. Stress was defined in this model version as those factors considered to most affect the maize growth cycle and for which input data are presently available to CCAD. Problem and optimal conditions that form the model logic are presented by growth stage in Table 1.

TABLE 1

GROWTH STAGE	DAMAGING CONDITION	OPTIMUM CONDITION
-1 - 0.1	Tavg < 9C AWC surface < 18%, > 90%	Tavg > 20C AWC survace > 50%, < 75%
0.01 - 1.0	Tmax > 38C Tmin < 0C AWC surface < 40%, > 95%	Tmax < 32 Tmin > 15C AWC surface > 50%, < 80%
1.01 - 2.5	Tmax > 38C Tmin < 2C AWC < 40%, > 95%	Tmax < 32C Tmin > 15C AWC > 50% & < 80%
2.51 - 4.75	Tmax > 38C Tmin < 3C AWC < 40%, > 95%	Tmax < 32C Tmin > 15C AWC > 55%, < 80%
4.76 - 6.5	Tmax > 33C Tmin < 5C AWC < 45%, > 95%	Tmax < 30C Tmin > 15C AWC > 55%, > 80%
6.51 - 8.0	Tmax > 38C Tmin < 0C AWC < 40%, > 95%	Tmax < 32C Tmin > 15C AWC > 50%, < 80%
8.01 - 10.00	Tmax > 41C Tmin < 0C AWC < 30%, > 95%	Tmax < 38C Tmin > 15C AWC > 40%, < 90%

2.3 STRESS CONDITIONS BY GROWTH STAGE

A. Growth Stage - 1.0-0.0. Climatic planting requires at least 18% available water in the surface layer with 65% being optimum. Corn germination is affected by both moisture and temperature. Mean daily temperatures of less than 9^{o}C will inhibit maize germination. Optimum conditions occur with daily mean temperatures greater than the 20C and available water capacities (AWC)[2] in the 50-75% range. Alerts are also issued at the stage for insufficient pre-season stored moisture. The bulk of corn is produced by dryland farming and normal precipitation is often insufficient. The amount of necessary stored soil moisture is location dependent. Tractability problems occur at plant and harvest when more than 5mm of precipitation falls or when soil moisture values exceed 80% AWC.

B. Growth Stage - 0.0-1.0. During the period from emergence until the collar of the fourth leaf is visible damaging conditions occur when temperatures drop below freezing of rise above 38C. The minimum moisture requirement is 40% AWC with values above 95% capacity also deterimental to sustained photosynthesis. Optimal conditions range from 15-32C with 50-80% AWC.

C. Growth Stage - 1.01-2.5. During the 4-8 leaf interval, damaging and optimal thresholds are identical to the emergence-4 leave period with the exception of cold tolerance; the minimum temperature is 2C.

D. Growth Stage - 2.51-4.75. From 8 leaf to effective cover, the plant is stressed by AWC values less than 40% or greater than 95%. Cold tolerance continues to decrease with temperature less than 3C being harmful. Optimum conditions are defined as being between 55-80% AWC and 15-32C.

[2] Available-water-holding-capacity (AWHC) can be defined in laymans terms as the amount of water that a soil will hold that is available to the plant. The technical definition states the AWHC as the difference between the upper and lower limits of the moist soil-water state or the difference between the field capacity and the permanent wilting percentage and is usually expressed on a volume basis when the bulk density is known. The concept of AWHC can apply to a horizon, layer or pedon. This can be expressed in terms of centimeters of water per specified depth of soil, as the two horizontal dimensions of the water and soil volumes are the same. Thus, the units of AWHC applied to characterize polypedons, or soil series are commonly expressed as centimeters (or inches) of available water per unit thickness (cm or inches) of soil, by horizon, or to the depth of rooting.

E. Growth Stage - 4.76-6.5. Maize is most sensitive to stress during the pollination period. Russian scientists have stated that even 2-3 hours exposure to excessive temperatures at silking will significantly reduce yield. Threshold for moisture are set at 45 and 95% AWC; temperature stress is defined at 5C and 33C. Optimal conditions vary from 55-80% AWC and 15-30C.

F. Growth Stage - 6.51-8.0. Stress values are relaxed somewhat after the pollination period. Adverse temperatures in the dough period are those below freezing and greater than 38C. Moisture requirements range from 40-95% AWC. Temperatures between 15-32C with 50-80% AWC are optimal.

G. Growth Stage - 8.01-10.0. The dry-down from full dent to physiological maturity is the final period checked in the model. The plant is very hardy and environmental impact on final yield is reduced. Stress conditions occur outside the 0-41C temperature range with AWC values less than 25% or greter than 95% signaling alerts. Optimal situations are expanded to 15-38C and 40-90% AWC. Freezing temperatures are most damaging to yield. Tractability alerts are generated from growth stage 9.0 to maturity.

PART 3.0 MAIZE STRESS INDICATOR MODEL

3.1 STRESS MODEL COMPONENTS

The stress model has 3 central components - a hazard model, a crop calendar model and a soil water budget model. These models collectively require daily meteorological data - maximum and minimum temperature and precipitation. The phenology-based hazard routine contains the stress definitions and thresholds. The crop calendar is a fixed-increment degree-day model developed by EW/CCA that requires an actual or estimated planting date. Degree-day summations are variety specific. A two-layer soil moisture model as implemented by Ravet and Hickman (1979) is employed to track the amount of plant-available soil water (Appendix 1).

3.2 DEGREE-DAY CALCULATION

Temperature is a regulator of maize growth and development. Most efforts to predict the timetable of maize development have used a heat-unit approach; the most common is the degree-day. The Brown method (1975) of determining degree days is based on the physiological response of plants to temperature and is determined as follows:

$$DD = (Ymax + Ymin) / 2$$

where $Ymax = (Ymax - 10^{o}C*[3.33-0.084*(Tmax - 10^{o}C]$ and $Ymin = 1.8*(Tmin - 4.44^{o}C)$. When Tmax is less than or equal to $10^{o}C$ the value of Ymax is zero and Tmax values greater than 32C are equal to 32C. When Tmin is less than or equal to $4.44^{o}C$ the value of Ymin is zero.

The values of the accumulated degree-days for the most common Soviet Union and Kansas/Oklahoma (in parenthesis) varieties are: 110 (146) to emergence, 420 (540) to HGS 1.0, 800 (990) to 2.5, 1380 (1665) to 4.75, 2085 (2770) to 8.0 and 2580 (3320) to 10.0.

3.3 MODEL PARAMETERS AND OUTPUTS

The model identifies three environmental conditions - optimum, adequate and hazardous. Hazardous conditions include:

(a) Insufficient pre-season stored soil moisture
(b) Planting/harvest delay (tractability problems)
(c) Poor germination
(d) Poor emergence
(e) Adverse growing season soil moisture and temperature (excessive/deficient, phenology-based)
(f) Optimal soil moisture and temperature conditions

The stress indicator model determines the possibility of maize stress based on temperature and moisture conditions (see Table 1). The stress and optimal growth conditions are recorded for each growth stage as well as the time the plant remained in these stages.

From this information the analyst can judge the degree of damage or stress occurring at a growth stage and than determine the overall effect on crop development. The model does not predict events nor does it attempt to assess the impact of stress, it provides information that indicates conditions occurring within a predescribed geographic area around the data source. The output from the model is a record of each day that a stress optimal condition has occured, the reason for the condition and the crop growth stage. At the completion of processing data for a given meteorological station, the data are summarized giving the total days for development, and the number of optimum and hazardous growth days.

PART 4.0 CONCLUSIONS

4.1 SUMMARY

A maize soil moisture and temperature stress model was developed by the Early Warning and Crop Condition Assessment component of AgRISTARS to support the Crop Condition Assessment Division of the Foreign Agriculture Service. The model is essentially a data filter that alerts a commodity analyst to corn producing areas that are under a potential stress condition due to adverse climatic conditions. The model also identifies areas of optimum climatic conditions and planting/harvest problems associated with poor tractability. The model has been tested over sites in the United States and Soviet Union under a wide range of climatic conditions with favorable results.

To assess the impact of alerts generated by the model requires the analytical skills of a commodity analyst well versed in agronomy and remote sensing. Future improvements in the model are expected to focus on phenology and spectral inputs.

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TWO-LAYER SOIL MOISTURE MODEL

The two-layer soil moisture model in use by CCAD and EW/CCA is similar to the Palmer two-layer model (Palmer, 1965). In the models, the amount of water withdrawn by both direct evaporation from the soil surface and transpiration by plants is determined by atmospheric demand and soil water availability.

Both models assumed that the first inch of available water is held in the layer. The actual thickness of each layer is variable depending on soil type, rooting depth and layers permeability.

The original Palmer model assumed that moisture was removed from the surface layer at a rate equal to potential evapotranspiration calculated by the Thornthwaite method (1948) and that moisture was removed from the lower layer at a fraction of the potential rate. It was assumed that moisture could not be removed from the lower layer until the surface layer was completely dry. These assumptions do not adequately represent the true layer condition.

The various stress indicator models being developed (Ravet and Hickman, 1979) required more accurate representation of the soil moisture condition, particularly in the surface layer. The two-layer model was modified to allow a more gradual and realistic depletion of the surface layer and also allows moisture to be depleted from the lower layer before the surface is completely dry.

SOIL MOISTURE EQUATION

Top Layer = Contains 1 inch of plant available water.

Lower Layer = Normally contains between 5 and 10 inches of available water.

$$L_s = S'_s - (PET-P)\ D_f$$

$$L_u = (PET-P-L_s)\ \frac{S'u}{AWC} : L_u \leq S'_u$$

D_f = Surface moisture extraction function.

$D_f = 1$ if P PET

$D_f = (S'_s \div .75) : .1 \leq D_f \leq 1.$

$D_f = .1$ if $D_f < .1$ and $D_f = 1. : D_f > 1.$

R = Excess P after both layers are filled.

PET = PET'(d) [Thornthwaite, 48]

If T less than 0°C
PET' = 0

If 0°C < T < 26°C
$PET' = 1.6\ (\overline{10T/I})^a$

If T > 26°C
PET' = Sin (T − 9.5) −.76

$$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + .01792I + .49239$$

$$I = \sum_{i=1}^{12} (T/5)^{1.514}$$

$$d = -0.767 \tan(.410117\cos(.0172264(JDAY-172)))$$

DEFINITION OF TERMS

L_s	=	Moisture loss from surface
S'_s	=	Available water in surface layer at start
PET	=	Potential evapotranspiration
P	=	Daily precipitation
L_u	=	Loss from lower layer
S'_u	=	Available moisture stored in lower layer
AWC	=	Combined available water capacity; i.e., $MAX(S'_s + S'_u)$
R	=	Runoff
D_f	=	Surface moisture extraction function
PET'	=	Unadjusted potential evapotranspiration
d	=	Day length adjustment for PET
T	=	Average daily temp degree C
I	=	Annual heat index
JDAY	=	Julian date
a	=	Coefficient

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